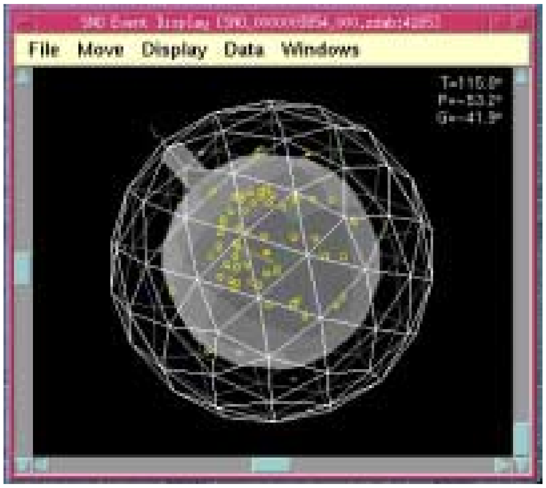

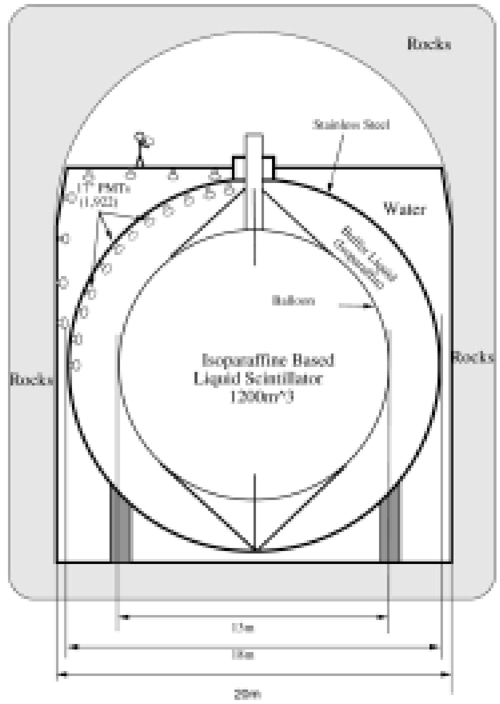

Fig. 1 (left) One of the first neutrino events from SNO.

Fig. 2. (right) Schematic view of the KamLAND detector.

Institute for Nuclear and Particle Astrophysics Overview

R.G. Stokstad

Introduction

The areas of research at the Institute (INPA) are broad and have a strong interdisciplinary flavor, yet a common purpose connects them - to use the science and the technologies of nuclear physics and particle physics to address fundamental questions bearing on the nature of the universe: past, present, and future. Specific research topics include solar neutrinos, high energy neutrinos, detection of nearby and distant supernovae, weak interactions in atomic and nuclear processes, the cosmic microwave background radiation, direct detection of dark matter, cosmic ray chronometers, the theory of pulsars and neutron stars, and geoastrophysics. Research and education are combined not only through the participation of students and postdoctoral researchers, but also at the high school level through summer programs for teachers and a major project, the Hands-On Universe, that brings on-line astronomical images to the classroom.

INPA is sponsored by the Nuclear Science Division and the Physics Division at LBNL. While participants in INPA are predominantly from these two Divisions, the Physics Department and the Space Sciences Laboratory at UC Berkeley are well represented. Indeed, the Institute benefits from the rich concentration of astrophysics in the greater Bay Area. A wide range of experimental facilities is used by INPA participants; at LBNL (the 88-Inch Cyclotron, Gammasphere, Low-Background Counting Facility, Leuschner Observatory), in North America (Sudbury Neutrino Observatory, the Keck Telescopes, nuclear physics facilities at national laboratories and university laboratories), throughout the world (Chile, Australia, Antarctica), and in space (Hubble Space Telescope). There is increasing interest in the study of neutrino properties and their use as probes of very energetic objects in the universe.

This overview naturally focuses on research where Nuclear Science Division-associated researchers are heavily involved. A few highlights from other areas are mentioned, and the overview concludes with a brief description of INPA's institutional activities.

Neutrinos and Neutrino Astrophysics

The Sudbury Neutrino Observatory (SNO), a 1,000-ton heavy-water Cherenkov detector located in a nickel mine in Canada, has completed its construction phase and began taking data in November of 1999. This past year saw a number of significant milestones reached. The filling of the detector with light and heavy water was completed the Spring of 1999. Since then water recirculation and other measures have resulted in a steadily declining level of background radioactivity. The target levels of U and Th in the light and heavy water have either been reached or are being approached at a satisfactory rate. These results indicate that the cleanliness program during construction was successful. Another milestone was the construction and installation of arrays of phototubes in frames that can be removed from the cavity for inspection. These tubes will be used for long term monitoring of submerged components, particularly the high-voltage connectors and optical reflectors. Attention at LBNL is now focused increasingly on calibration (^{16}N, ^{17}N, and (p,t) sources, activated NaI and LED light sources) and data analysis. Analysis is proceeding rapidly with the goal of a preliminary result on the charge-current solar neutrino rate by mid 2000.

The same properties of neutrinos that make them a valuable probe of the sun could also make them a unique window on the most energetic objects in the cosmos. A number of INPA participants are members of the AMANDA collaboration, which is constructing a water Cherenkov detector in deep Antarctic ice to observe high energy neutrinos. With 13 strings of PMTs operating AMANDA has detected up-going muons, the signature of high energy neutrinos. Several hundred atmospheric neutrinos have been detected so far in an analysis of data take in 1997. This season at the South Pole (99-00) six more strings were deployed, one of them a "digital string" having 41 Digital Optical Modules. The digital system is being developed at LBNL as an R&D project to demonstrate this technology for IceCube, the kilometer-scale neutrino detector proposed as the successor to AMANDA. This future detector should have the sensitivity to detect neutrinos from distant point sources, such as Active Galactic Nuclei or Gamma Ray

Bursters. INPA, with cooperation from NERSC, is also heavily involved in the analysis of the large amounts of data generated by the current array. INPA is also making a major contribution in the planning and R&D toward the next generation neutrino observatory.

The properties of neutrinos, in particular, whether they have mass, are of fundamental importance to astrophysics and cosmology, as well as to the standard model of particle physics. SNO is a prime example of a neutrino oscillation experiment. KamLAND, a detector under construction in Japan, is another. The U.S. collaboration for KamLAND has formed and is now actively involved in a number of important aspects of the design and construction. LBNL is a major participant. KamLAND will use 1200 m^3 of high purity liquid scintillator to detect anti neutrinos from nuclear power reactors over 100 km away. This long baseline provides a sensitivity to neutrino oscillations that extends down in _m^2 to a region also covered by SNO (the "large mixing angle" solution." The question of neutrino mass is also addressed by the double beta decay experiment CURORE, which is planned for the Gran Sasso underground laboratory. LBNL is involved through its Materials Science Division by developing the NTD Ge thermistors that detect and measure the energy of the two electrons emitted in the decay of ^{130}Te, and the Low Background Counting Facility, which examines the components of the detector for trace amounts of radioactivity.

Nuclear Astrophysics

Knowing the half life of unstable (but long-lived) nuclei present in cosmic rays makes it possible to determine the residence time of these nuclei in our galaxy, i.e., they can serve as a cosmic chronometer. In this case, the half lives need to be of the order of 10^6 years. The half-lives of ^{44}Ti, ^{56}Co, and ^{57}Co in young supernova remnants can be substantially altered from their laboratory values because of the high temperatures and low densities found in these environments. On the other hand, the decay rate of a nucleus in space (where it has no surrounding electrons to capture) can be much longer than when it is housed in an atom or ion on earth. Measurements of very weak _$^+$ decay branches are therefore necessary. ^{144}Pm and ^{54}Mn and ^{56}Ni are three such cases; the latter nucleus is of particular interest because it has recently been possible to measure the relative abundance of the Mn isotopes in cosmic rays. Finally, an accurate determination has been made of the intensities of the γ-rays emitted in the decay of ^{66}Ga. The high-energy γ-rays emitted by ^{66}Ga are extremely useful for calibrating the efficiencies of germanium detectors, and the published intensities had been called into question.

Data for Nuclear Astrophysics

Nuclei heavier than lithium can only be made in stars, and in the later, rapid burning and explosive stages of stellar evolution. The prediction of the abundance of these nuclei is a triumph of nuclear astrophysics, and requires an amount of nuclear information on a similarly grand scale. INPA, the Isotopes Project, and UC Santa Cruz have assembled a number of the data-bases used in nucleosynthesis calculations and made them available to the community through our new Nuclear Astrophysics Data Home Page. The type and range of data available through this site has continued to grow as has the number of visitors to the web site.

Weak Interactions and Fundamental Measurements

The standard model of particle physics is the cornerstone for understanding the origin and development of the universe. Many of the key elements or parameters of the standard model are reflected in nuclear properties and measured in precision low-energy nuclear (or even atomic) experiments. It is possible to establish, test, and look for physics beyond the standard model in these experiments. Parity non-conservation, second class currents, time reversal invariance, the conserved vector current theory, double beta decay - these are some of the topics studied in the physics of weak interactions.

Progress continues to be made in a series of experiments involving ^{21}Na (laser trapping, parity non conservation), neutron decay (time reversal invariance and parity violation), ^{14}O and 14C (test of the CVC hypothesis) ^{10}C (unitarity of the CKM matrix), and Yb (atomic parity non-conservation).

Low Background Counting

The Low Background Counting Facilities used in the study of __ decay have also been instrumental in a wide variety of experiments and in support activities for other institutions. The other types of work (done at the facilities at Berkeley and at Oroville) include low-activity materials certification, cosmic ray activation, neutron activation analysis, and environmental health and safety activities.

Astrophysics and Cosmology in the Physics Division

We mention here two INPA projects that address the early history and the ultimate fate of the universe and which are based in the Physics Division. The cosmic microwave background radiation observed today reflects the state of the universe about 3×10^5 years after the Big Bang, at the time radiation and matter decoupled. The next generation of satellites, to follow COBE in the study of anisotropies in the CMBR, are being planned.

The fate of the universe depends on its matter density, which is expressed as a ratio to a critical density at which the expansion rate of the universe slows to zero at infinite time. The supernova cosmology project searches for (and regularly discovers!) type 1A supernovae at very large distances. In essence, the luminosity of a type 1A supernova is a constant or "standard candle," which gives its distance, and the red shift of its host galaxy gives its velocity. Thus, the Hubble diagram can be extended to very large distances (or far back in time). Deviations from a linear dependence of recessional velocity on distance have indicated that _ $_M$ (the ratio of the mass density of the universe to the critical value) is substantially less than 1 and, equally momentous, that the cosmological constant, _ $_\_$, originally proposed by Einstein and later retracted, is finite. The small value of _ $_M$ and finite _ $_\_$ imply that the universe will expand forever. A proposal for a space telsecope, called SNAP and to be dedicated to the deep search for Supernovae, has been submitted.

Institutional Activities

The purpose of the Institute is to further interdisciplinary work in Nuclear and Particle Astrophysics at LBNL by:

• promoting interaction and communication among its members

• sharing of intellectual, technical, and administrative resources

• planning of new research proposals and development of detector systems

• developing innovative educational outreach programs

• establishing seminar, postdoctoral, and visitor programs

• sponsoring of workshops

The list of active participants has grown to approximately 90, while the number of people receiving e-mail announcements of the weekly Journal Club is ~200. Attendance at the Journal Club is typically 30-40 people. The daily tea has become an established feature of INPA life and attracts usually 15-20 people -students, post-doctoral fellows, and staff - for conversation and lively argument. The Common Room is heavily used for regularly scheduled group meetings and ad-hoc get-togethers. The list of Journal Club speakers is contained elsewhere in this Annual Report.

INPA hosted or co-hosted the following meetings and/or workshops:

February 20-22, 1999: Site visit by an NSF committee reviewing the UC/LBNL proposal for a "Deep Ice Science and Technology Center" (co-hosted by the UC Berkeley Physics Department).

April 7-11, 1999: Meeting of the AMANDA collaboration.

October 15, 1999: Meeting to develop an IceCube cost estimate for an NSF management review.

November 1-14, 1999: Isotopes Project Workshop

December 2, 1999: Meeting on Standards for Robotic Control of Telescopes Over the Internet.

January 10-11, 2000: DoE "Lehman" review of the KamLAND proposal.

Visitors are invited to spend time from a week to several months at the Institute. This year's visitors included:

Thomas Fisher-York (Supernovae Cosmology Project) 2/8/99-12/31/99

Michael Shane Burns (Supernovae Cosmology Project) 5/20-6/5/99

Ariel Goobar (Supernovae Cosmology Project) 5/24-6/11/99

Iuda Goldman (Nuclear Astrophysics) 6/17-8/15/99, 1/20-1/30/00

Munther Hindi (Nuclear Astrophysics) 6/28-8/15/99

Alejandro Garcia (Weak Interactions, Nuclear Astro.) 7/1/99-12/24/99

Gabor Molnar (Isotopes Project) 9/19-10/2/99

Jean Blachot (Isotopes Project) 10/1-10/31/9

Daniel DiGregorio (Nuclear Astrophysics) 12/2-12/24/99

Maurice Goldhaber (Institute Distinguished Visitor) 1/22-1/27/00

Chris Bebek (Supernova Cosmology Project) 3/1/00-3/31/01

Additional information on the Institute and its activities can be found on the World Wide Web under the URL http://www-inpa.lbl.gov/.